7b - Stream Simulation Design

Stream Simulation Design Process

Assessment
Stream simulation feasibility

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Project alignment and profile

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Verify reference reach

↓

Bed shape and material

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Structure width, elevation, details

↓

Mobility / stability

↓

Design profile control →

- Project objective
- Simulate reference channel bed material
- Margins, banklines, forcing features
- Bed forms, shape

Bed Design Objectives

- Simulate natural bed
  - Shape
  - Diversity
  - Roughness
  - Mobility
  - Grade control
  - Energy dissipation
  - Control permeability

Roughness Elements

- Bed material particle-size distribution.
- Channel shape.
- Bedforms (fixed or mobile).
- Key features that constrict the channel and are major roughness elements.
- Vegetation.
- Bank irregularities.
- Channel bends (not generally considered)

Roughness = AOP

These elements control channel gradient and provide enough **flow resistance** (roughness) to maintain the diverse range of water depths and velocities needed for fish and other aquatic species passage.

Stream Simulation Bed Elements (building blocks)

- Particle-size distribution of the bed material.
- Channel width and cross-section shape.
- Rocks size and gradation for creating banks
- Bedform size and arrangements to mimic step-pool, pool-riffle, or other sequences.
- Size of key features: boulders, logs (downstream channel)

Features based on Montgomery and Buffington

Channel Types:

- Cascade channels
- Step-pool channels
  - Forced channels
- Plane-bed channels
- Pool-riffle channels
- Dune-ripple channels

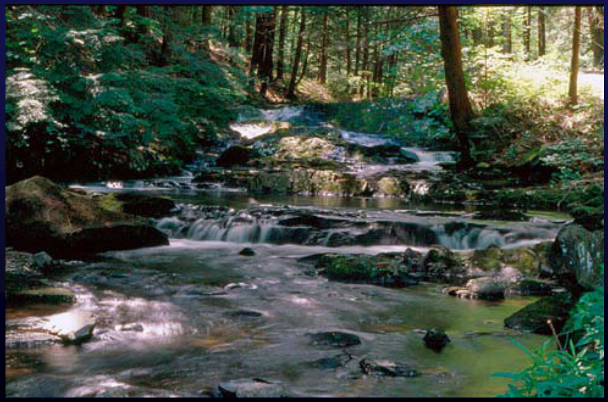
General trend: Increasing slope = Decreasing mobility but depends on so much more……

Special Cases:

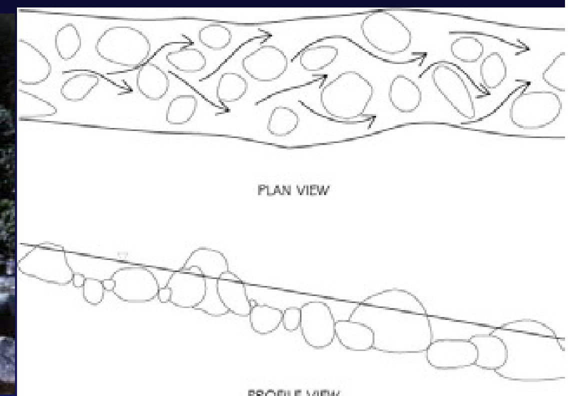
- Bedrock channels with veneers of sediments
- Channels with cohesive bed material

Typical Grade Control & Energy Dissipating Features

	Boulder Clusters	step & pools	steps	scattered Boulders (Colluvium)	riffle	gravel bars	large wood	frequent & persistent small wood
Cascade	X	X	X	X			X	
Step Pool	X	X	X	X			X	
Plane Bed	X		X	X			X	X
Pool Riffle - high stability				X	X	X	X	X
Pool Riffle - low stability				X	X	X	X	X
Dune Ripple					X	X	X	X



Cascade Reach



The large particles that form the bed mobilize only during very large floods (50- to 100-year flows),

- Steep slopes of about 10- to 30-percent slope
- Frequently confined by valley walls.
- Tumbling, turbulent flow over the individual disorganized cobbles and boulders scattered or clustered throughout.
- Small pools do not span the entire channel width

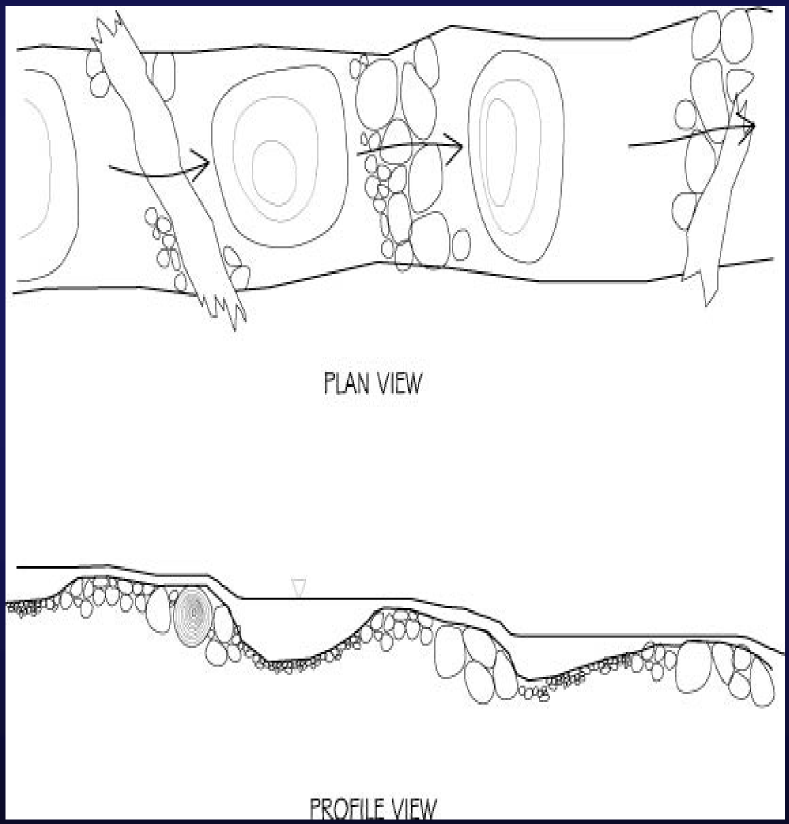
Cascade Reach Solutions

- Surface pebble (boulder) count based gradation
  - Achieving both stability and low permeability are primary concerns
  - Finding a good source for material of adequate size and density is important. Sorting and Mixing (Hydrologist!)
  - Angular rock may be desirable for stability
- Addition of large steps helps stability and grade control
- Construction is perhaps most critical of all channel types
  - Very large well graded material may be a challenge to produce
    - Verification by pebble counting techniques
    - More difficult to achieve good interlocking similar to the stream
  - Machine placement benefits from addition of vibration plate compactors mounted on excavator

Example of Cascade Design

- Design using D-84 of 36”, rough surface as placed
- Raised banks reinforced with additional large boulders
- Additional large boulders for added bed grade control

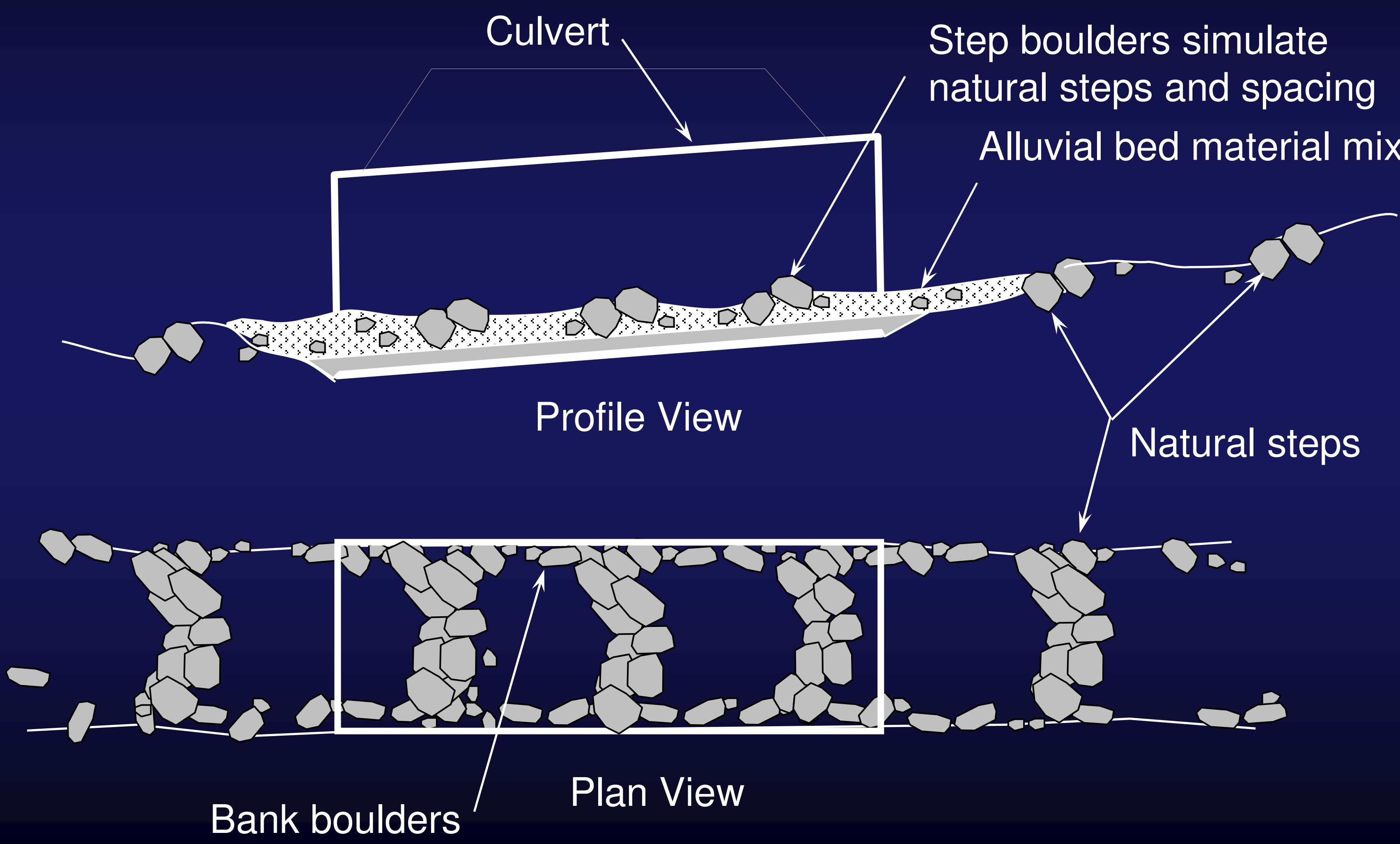
Step-pool Reach
Boulder Creek, Colorado



Step-pool reaches

- Large rocks and wood form channel-spanning steps
- Usually spaced at about one to four channel widths.
- Energy is efficiently dissipated as flow falls into the pools
- Bed structure is more stable than a less organized streambed.
- Steps mobilize and reform during large floods (may be more frequent when bedrock is relatively shallow)
- Finer sediment moves over the steps during moderate high flows. (as it does in all channels at various flows)
- Typical average channel slopes range from 3 to 10 percent slope.

Step Pool Solutions – Build steps/step-pool structures

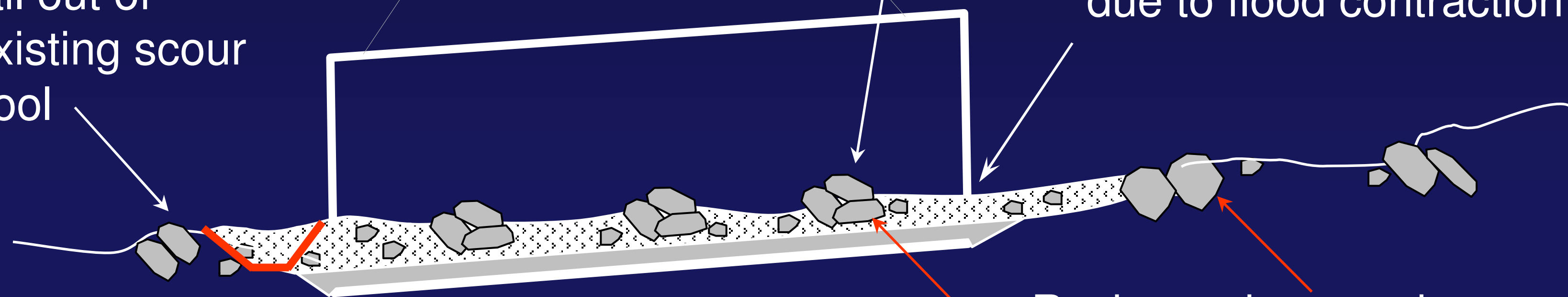


Other Specific Step Location Considerations

place first step inside ½ bfw-1bfw

Consider one step to reinforce tail out of existing scour pool

Inlet vulnerable to scour due to flood contraction



Rocks my be round or tabular

Step pool channel

Helpful hint:

Mark step locations and thalweg/bank elevations on culvert wall or concrete footing

Step Pool Example Big Creek, Oregon

Forced step pool reaches

- Wood forces the channel into step pool morphology
- If wood were not present, channel would be different
- Wood may not persist for life of structure
- Different elevation of streambed and water level results
- Underlying natural Bedform

can be any:

  - Cascade
  - Step pool
  - Plane bed
  - Pool riffle
  - Dune Ripple

This one

Forced Channel Solutions

- Even large wood may be temporary compared to your structure.
- New wood falls in different location, forcing the stream differently
- Associated Restoration Considerations:
    - Stream has adjusted to steps,
    - restore channels to similar grade control spacing using steps to reinforce wood grade control locations
  - Stream Simulation:
    - Build steps to mimic wood grade controls and stabilize stream simulation bed when wood finally deteriorates.

Wood Forced Channel

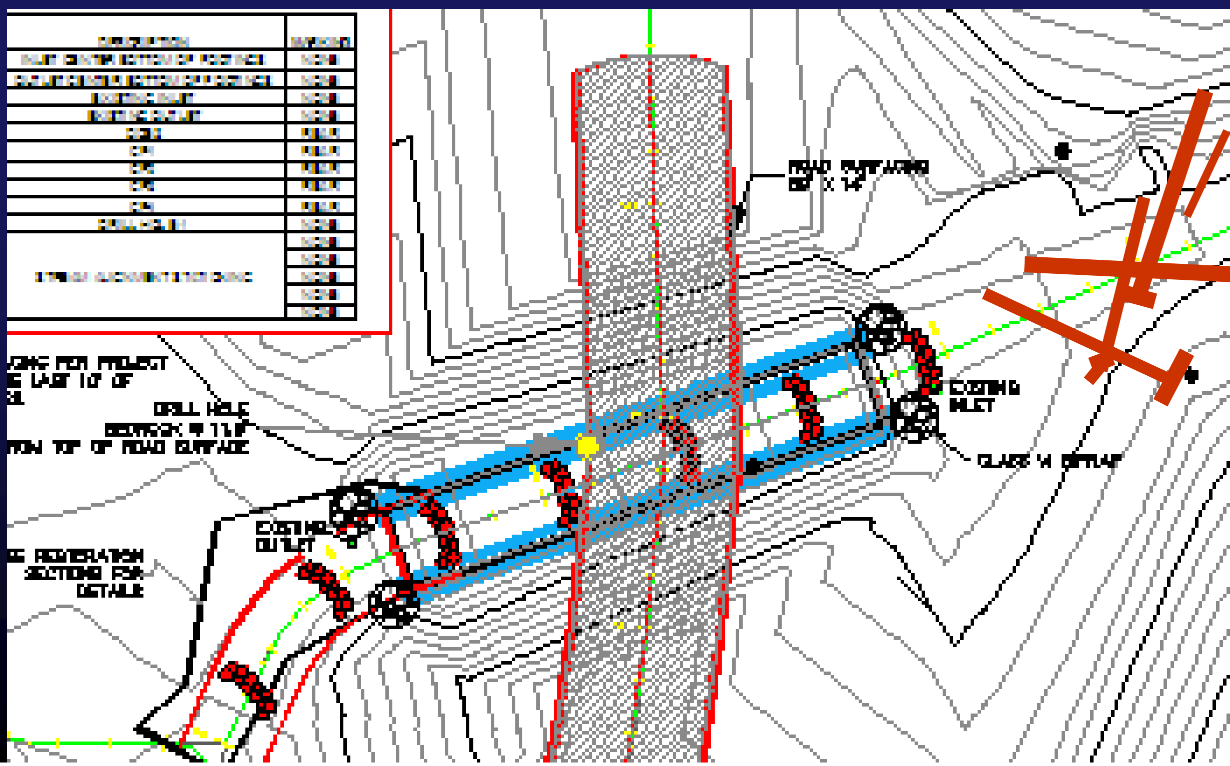
Mag Creek, Mt Hood NF, Oregon

McGlynn Ck, Siuslaw NF, Oregon

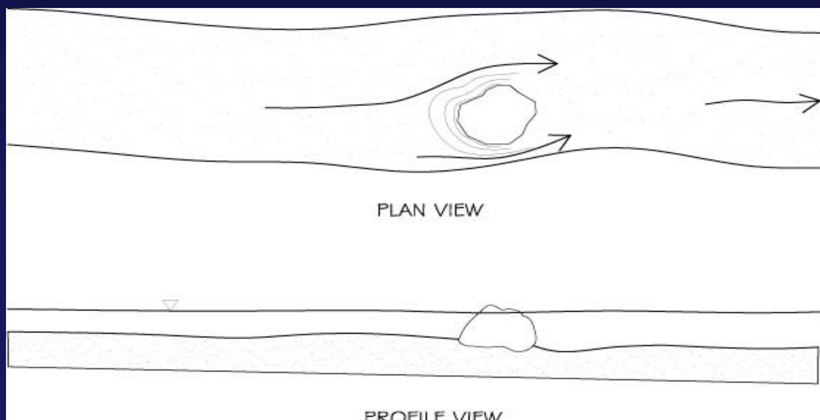
Wood Forced Channel Solution:

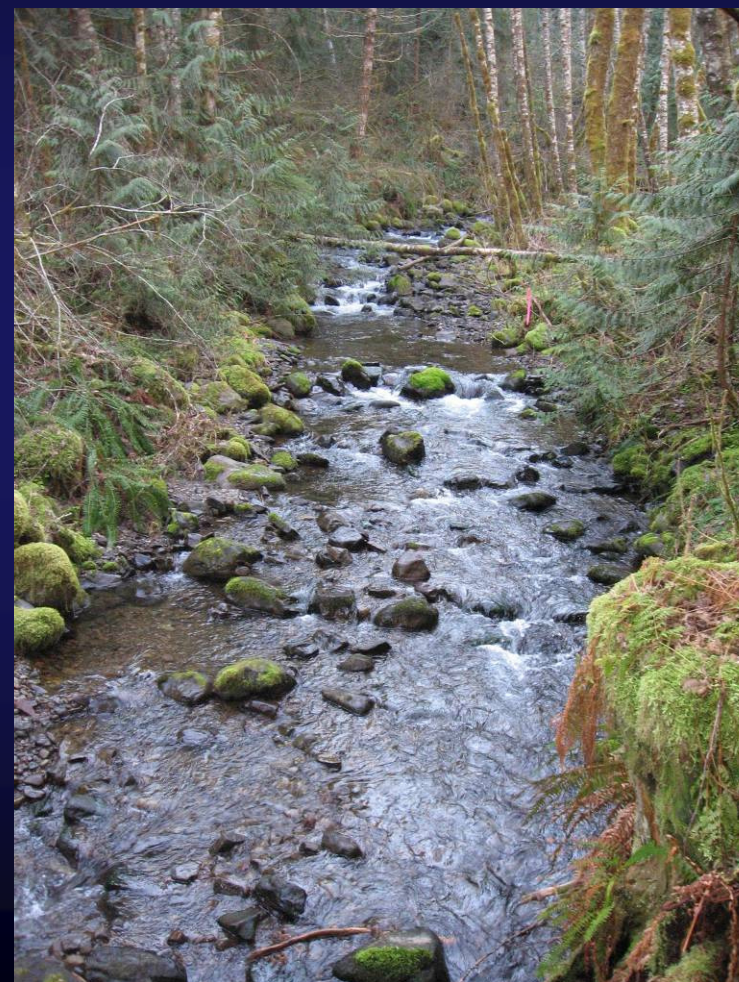
Based on underlying channel characteristics and gradient

- Rock step spacing in culvert and restoration area equal to wood step spacing upstream
- Alternative solution could be a short riffles or stable gravel bars spaced at wood spacing



Plane-bed channel
Sitkum River, Washington.





Plane-bed Channel

- Long stretches of relatively featureless bed without organized bedforms.
- Moderate to high slopes in relatively straight channels,
- Usually with armored gravel-cobble beds.
- Bed mobilization occurs at flows near bankfull.
- Infrequent grade controls that not be important to mimic:
  - Colluvium / Key pieces in clusters or high frequency
  - Changes in stability due to variations in armor
  - Small Steps without pools, Large or small wood

Plane Bed Solutions

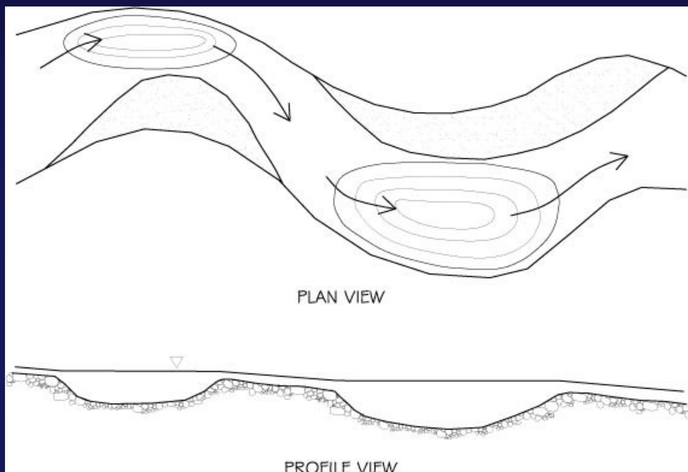
Constructed armored stream simulation bed using:

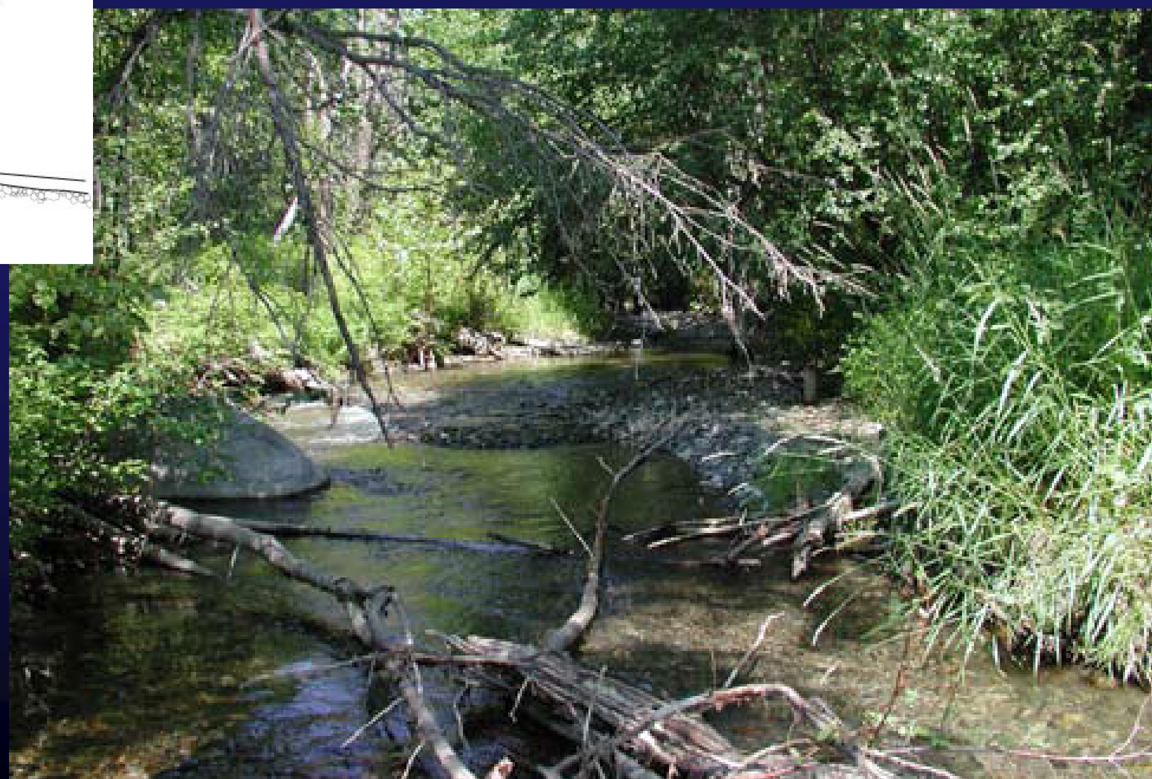
- Stream simulation material and
- added boulders for roughness

Plane Bed Stream Crossing

Note that small wood does have a role, especially with multiple culvert installation

Pool-riffle reach: Libby Creek, Washington.





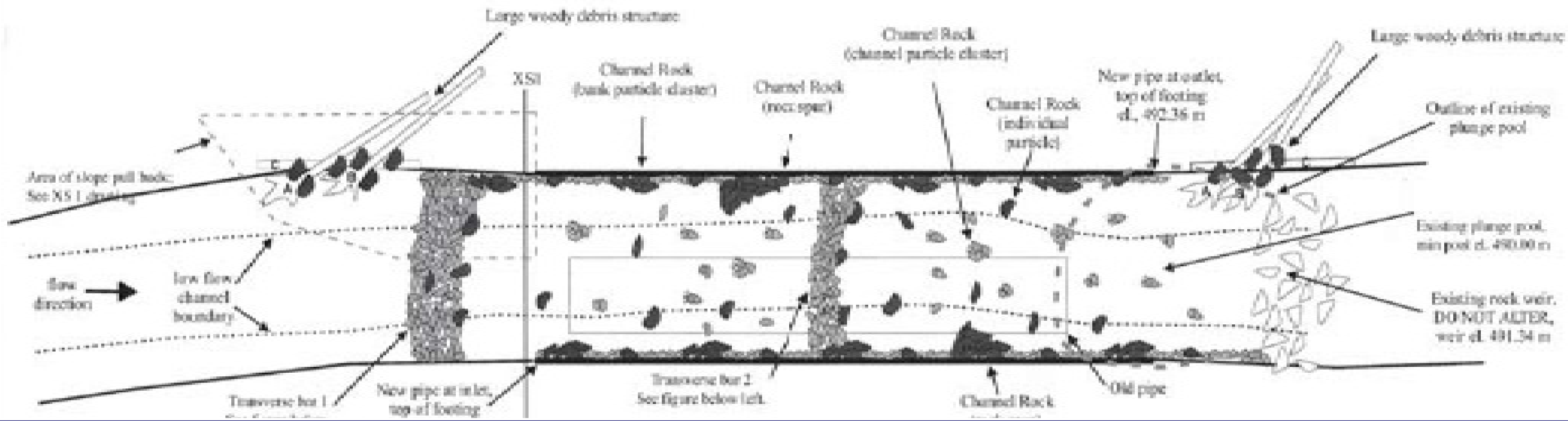
Pool-riffle reaches

- Have longitudinally undulating beds,
- A repeating sequence of bars, pools, and riffles regularly spaced at about 5-to 7-channel widths apart.
- May be sand to cobble-bedded streams. Large woody debris can alter the spacing.
- A flood plain is usually present

- Depending on the degree of armoring, bed mobilization may occur at or below bankfull.
- Or less frequently due to greater armoring
  - Frequent colluvium/Key pieces also controlling grade
  - Changes in gradation resulting in better armoring in a reach (think of exciting channels you have rafted)

Pool Riffle Solution

Riffles, banks and scattered boulders



Pool Riffle Solutions

Associated Restoration With Large Wood

Associated Restoration With Constructed Riffles

More suitable in urban areas with more predictable results

Newbury Riffle

Dune-ripple reach: Coal Creek, Washington.

- Have low gradients with sand and fine gravel beds.
- Transports sediment at virtually all flows
- Bedform change depending on water depth and velocity
- If sinuous, these streams also can have point bars.
- Easily effected by a head cut or loss of grade control

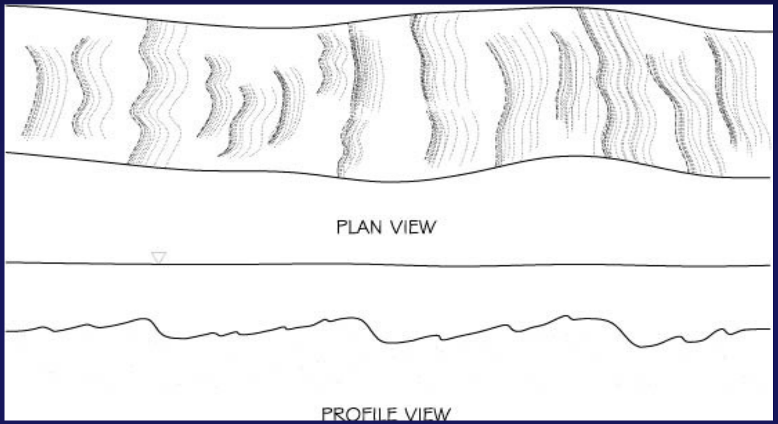


Photo: Kozmo Ken Bates.

Other Possible Grade Controls

- Large or small wood
- Durable to non-durable colluvium / key pieces
- Changes in gradation
- Colluvium
- Tides
- Downstream coastal beach variation

Sandbed/Dune Ripple Solution

- May want to armor channel and reach if not backwatered
- If abundant sediment supply, infilling may not be necessary
- Rowdy Creek: Sand to clay bed with tidal influence, soft sandstone bedrock, beaver dam upstream

Armored beneath, gravel bed constructed over top

limited head cut when beaver dam failed

downstream channel

Bedrock Reach

Bedrock Reaches

Bedrock channels exist

- where a bed of alluvial material has scoured off of bedrock
- where woody debris has been removed
- where a debris flow has scoured the channel to bedrock.

- Bedrock that does not show typical erosional features, such as fluting, longitudinal grooves, or potholes,
  - could indicate an alluvial veneer has recently washed away.
  - Recent channel incision due to channel realignment or straightening
- Large wood and sediment veneers and colluvium may be important grade features for enabling AOP.

Bedrock Reaches Solutions

Stream realignment & restoration may be appropriate

Stream simulation:

- Consider using large wood downstream to trap sediment
- If it is determined the channel could be raised (long profile) a stream simulation channel can be built.
  - Base design on appropriate design for the gradient while considering bedrock key features.
- If not raised, use large immobile boulders to trap sediment in the structure and downstream.
  - Set boulders in bedrock depressions or anchoring in place with dowels

Example: Bottomless arch for maximum bed thickness

D-100 = 8” in channel

14-20” boulders placed on bedrock surface to help trap sediments

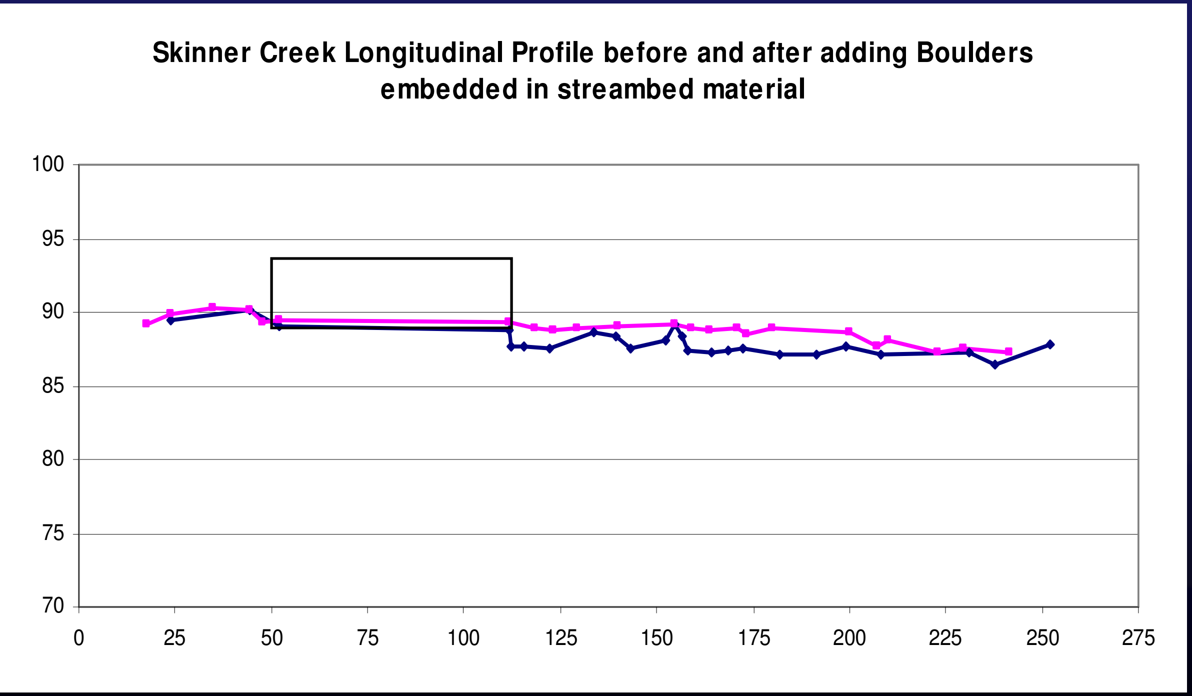
Boulders stable @ Q100

Gradient 1.4%

Thin substrate Over Bedrock

Retrofit of bedrock channel / 1.2% Pool Riffle Channel

2004



Cohesive Bed Reach

We really don’t know much cohesive stream channels beds

- What are your experiences?

- What we’ve heard
  - Beds consisting of primarily of fine sediments of high plasticity silt or clay
  - Gradients usually very flat and they are usually backwatered
  - If dried, desiccation cracks can cause flaking, entrainment, incision
  - Wood may be important grade control
  - You can’t build them (stream simulation guide)

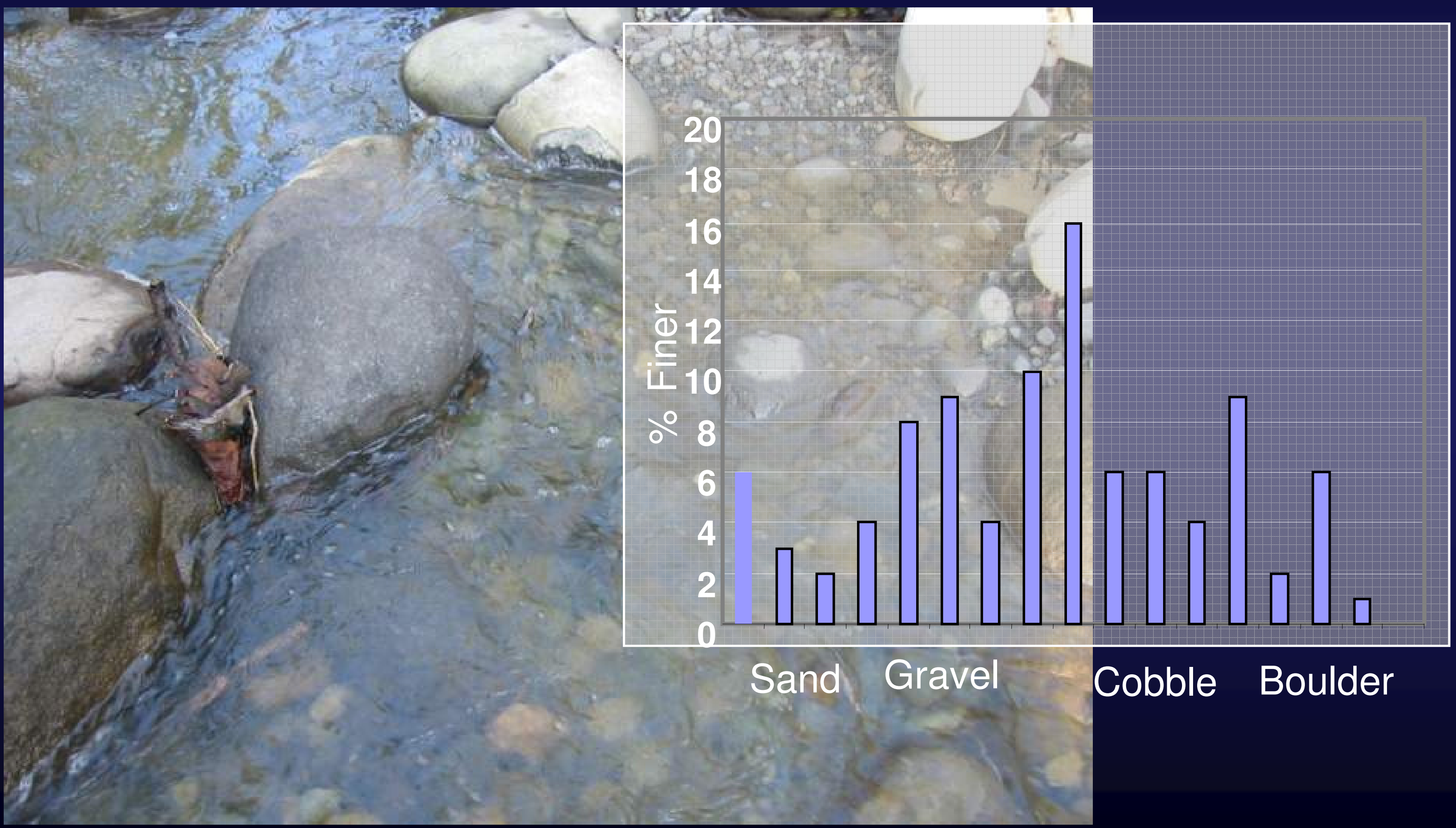
Suggested Cohesive Bed Reach Solutions

- Actually you could build a cohesive bed, assuming the site is dewatered, imported material is at optimum moisture, and is shaped and compacted with appropriate equipment.

- Best to leave undisturbed by bridging bank to bank
  - Construction drying (dewatering) can cause shrink/swell problems
  - Engineering properties vary considerably
  - If the channel is backwatered, a wide culvert might work by pacing on the existing bed and leaving it unfilled

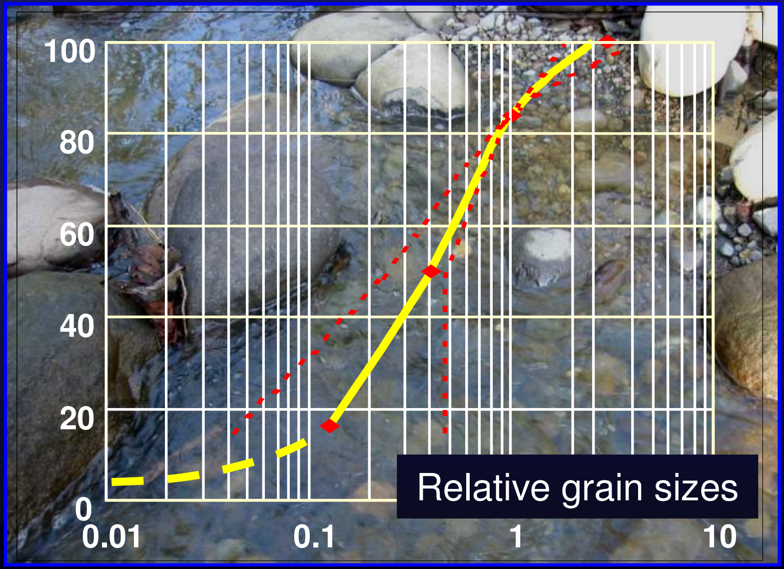
- Culvert Replacement,
  - channel offset restoration may often be required
  - Use hydraulic flow and stability analysis to design a restoration grade using stream simulation rock and grade control.
  - Wood placement may be a key grade control

Well-graded Bed Material



Bed Material Design – Alluvial

- New installations: use undisturbed channel (consider contraction)
- Replacements: use reference reach gradation.
  - Pebble count of reference channel for D_{95}, D_{84} and D_{50}
  - Include dense gradation based on D50 for smaller material and impermeability.
  - Fine-grained beds are special cases.
  - Compensate for stability of initial disturbed condition.
  - Account for large roughness and forcing features.



Bed Material Design - Alluvial

Larger particles sized directly from reference channel

Small grains derived by Fuller-Thompson curve based on D_{50}

Fuller-Thompson

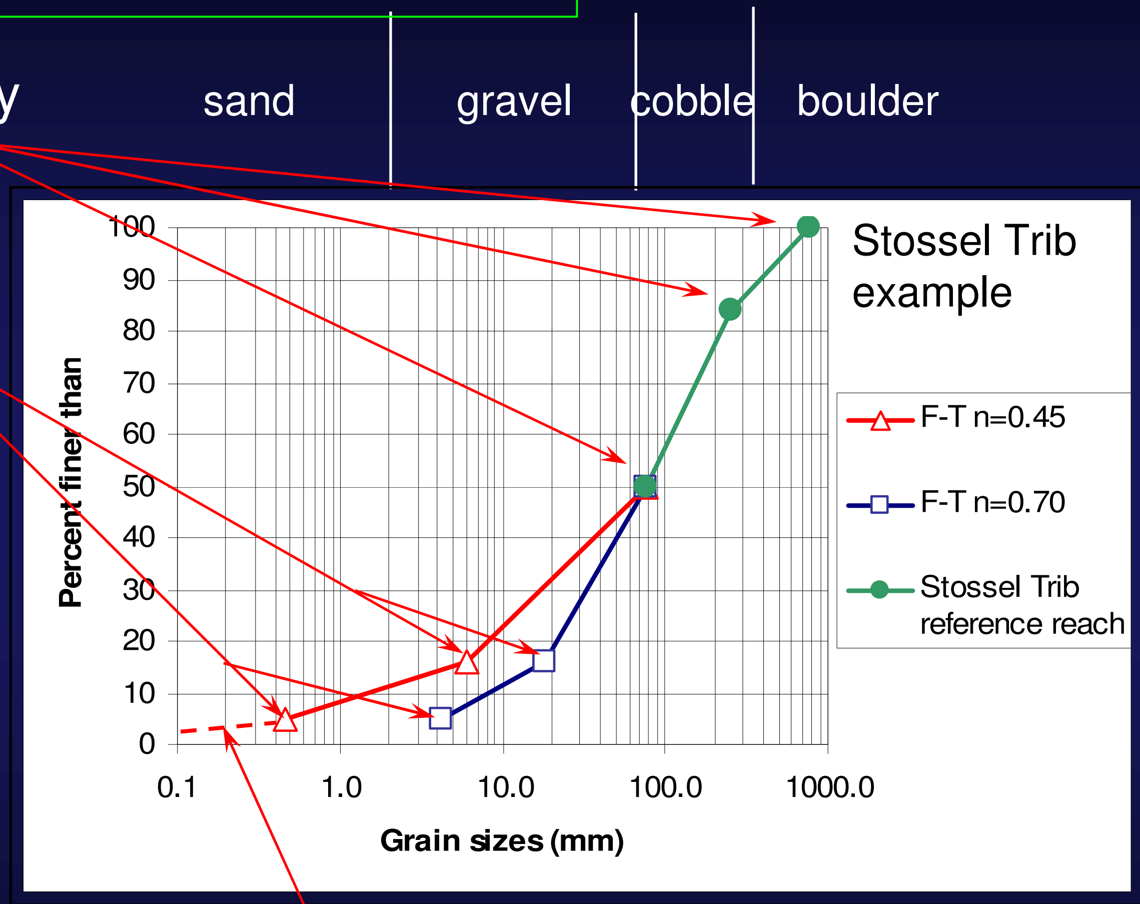
$$P = \left[\frac{d}{D_{100}}\right]^n$$

P = percent finer
d = diameter of particle
n = Fuller-Thompson density; varies 0.45 to 0.70

Simplify to:

$D16 = 0.32^{1/n} \times D50$

$D5 = 0.10^{1/n} \times D50$



Verify 5% fines are included

Bed Material Example
W Fk Stossel Cr

	Reference	Strm Sim	Fuller-Thompson n=0.7
D95	30”	30”	6.7”
D84	10”	10”	5.2”
D50	3”	3”	3”
D16	?		0.59”
D5	?		0.11”
Fines	?	5-10%	

$= 0.32^{1/n} \times D50$

$= 0.10^{1/n} \times D50$

Which is:

50% cobble and boulder
34% gravel
16% medium gravel and fines

Bed Material Example

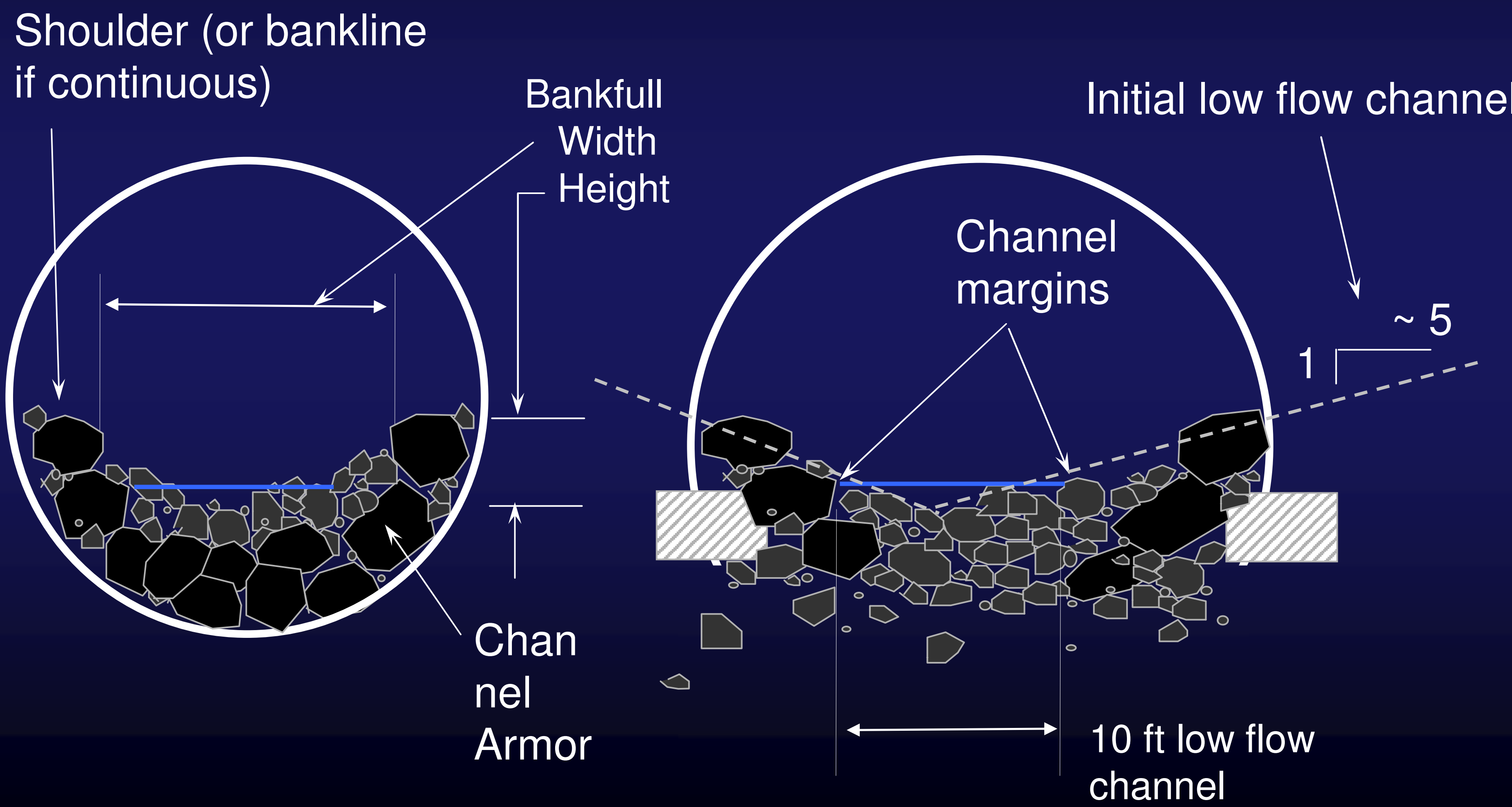
- 1 scoop bank run dirt
- 4 scoops 4” minus pit run
- 4 scoops 8” minus cobbles (or quarry rock)
- 2 scoops 1.5’ minus rock
- 1.5 to 2.5 foot rock added during installation

W Fk Stossel Cr – 6.4% slope

Review - Mimic features in the reference reach

- From site assessment we will have:
  - Channel restoration and bank stabilization guidelines in upstream and downstream channel segments
  - Stream-simulation bed material gradation
  - Grade control and key feature size, arrangement, frequency
  - Channel shape and dimensions

Stream Simulation Bed
Channel cross-section



The Role of Stream Banks

Uniformly important for fish passage and restoration:

- Vegetation and gradation of banks determine stability.
- Culvert banks mimic these features using stable rocks.
- Creating shallow margins for juvenile and adult species.
- Top of banks can aid terrestrial passage.
- Protect footings by preventing edge scour and “gullying”

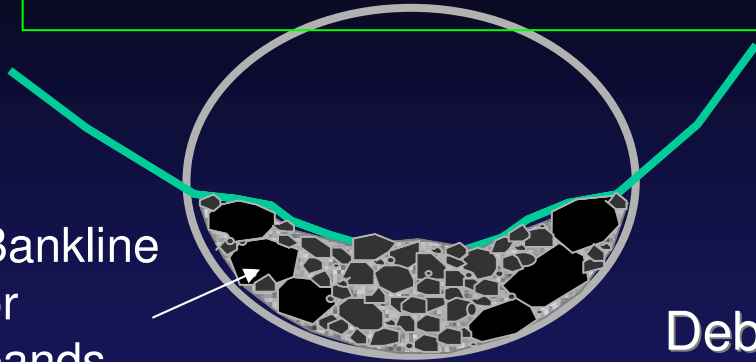

Low slope without bedform or banklines

Without stable banks, flow concentrates toward the side and can scour footings, concentrate flow and create a barrier on steeper streams

Shallow flow margins are important for some organism to move upstream

Margins, Banklines

Bankline or bands



Debris

Bank diversity = Roughness

Bank stability – Root Strength
What do you use in the culvert?

Bed material example design and spec
W Fk Stossel Cr

	Reference	Design
D95	30”	30”
D84	10”	10”
D50	3”	3”
D16	?	0.6”
D5	sand	0.1”
Fines		5-10%
Colluvium, debris	Spanning 6-12” debris at 50’ spacing	24” rock scattered at 15’ oc throughout
Banklines	Bankline root structure protrudes 3’ at 25’ spacing	36” bankline rock at 25’ spacing or continuous each bank

Banks and key pieces

- Use reference channel modify for construction in structure
- Stability analysis may be necessary due to actual gradient of structure

Tire Creek
Willamette Nat'l Forest

Blue Creek
Lolo Nat'l Forest

Bed material in channels with small grain material

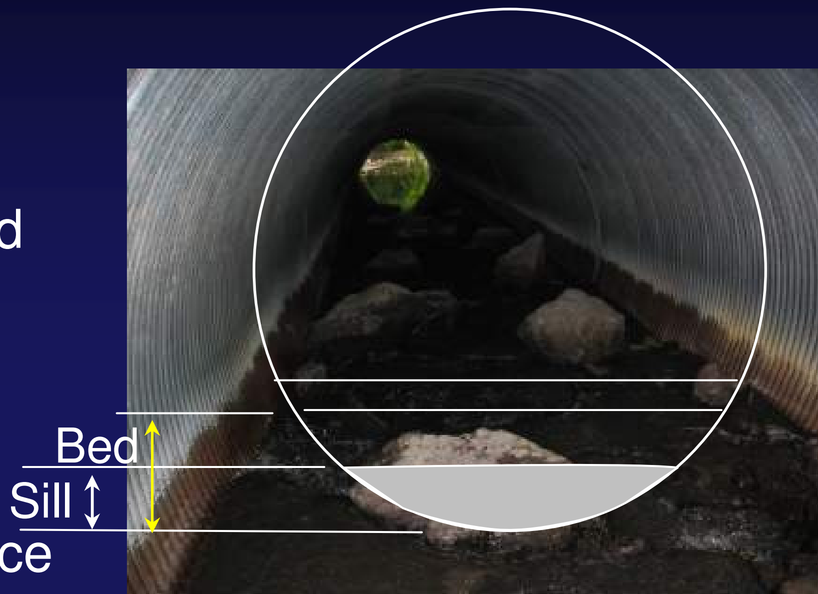
- Lower risk with bed higher mobility
- Less practical to design detailed bed material
- When D84 < 20 mm
  - Use natural bed material
  - Select borrow
    - Does bed satisfy objective?
  - If mobile, allow natural filling
    - Risk of timing, headcut?
    - Consider volume of culvert fill
    - Channel constriction could be significant issue
    - Consider temporary sills to retain bed

Example spec

Select Borrow	
Sieve size	% by weight
75 mm	100
25 mm	70 – 100
4.75 mm	30 – 70
150 um	0 - 15

Bed Retention Sills

- Bed retention sills are not baffles or weirs
- Anchors bed; keeps bed from sliding out of culvert, improves stability of bed
- Can help retrofit culverts where no other option is available
- Main objective is to hold a layer of stream bed material in place
- In turn that holds more material in place
- Good use is where bed is thin due to bedrock and stream bed elevation limitations on long profile.
- Recommended maximum height equal to half of depth of bed or ½ of largest diameter pieces
- A bottomless arch may be a better choice



Last thoughts on bed material

- Stability and permeability are key to design of bed
- Carefully select and supervise source, mixing, and placement
  - Pebble counting techniques work on stockpiles
  - Use a traverse and x-sections for 100 points, ignore excess fines (that would be primarily subsurface)
- Round vs. angular rock?